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DOCUMENT I. - REPORT

ABSTRACT

Nowadays unmanned aerial vehicles (UAVs) have many applications in very different fields: agriculture, photography, filming, sampling, surveillance… and technology is progressing according to the needs of the market. The use of this technology is increasing due to the ease of adding sensors and mechanical devices to collect data where any other traditional methodology would require more cost, time and waste of resources.

The aim of this project is to develop a system based on UAV technology which main task is to take samples from drinking water sources to analyse them later. This task is necessary to evaluate the water quality, and doing so using UAV technology permit to obtain the results by reducing the cost and time, as well as working in places where it would be difficult to do it in the traditional way.

Within in this project it has been designed a water sampler to take samples of 500 ml volume and the hardware and software necessary to control the sampler remotely from another device, by using a microcontroller attached to the aircraft.

RESUM

Actualment, els vehicles aeris no tripulats (UAV) tenen moltes aplicacions en camps ben diferents: agricultura, fotografia, rodatge, mostreig, vigilància... i la tecnologia està avançant segons les necessitats del mercat. L'ús d'aquesta tecnologia està augmentant degut a la facilitat d'afegir sensors i dispositius mecànics per recopilar dades on qualsevol altre metodologia tradicional requeriria més cost, temps i malbaratament de recursos.

L'objectiu d'aquest projecte és desenvolupar un sistema basat en la tecnologia UAV, la tasca principal del qual és prendre mostres de fonts d'aigua potable per analitzar-les més endavant. Aquesta tasca és necessària per avaluar la qualitat de l'aigua, i fer-ho mitjançant la tecnologia UAV permet obtenir els resultats reduint el cost i el temps, així com treballar en llocs on seria difícil fer-ho de manera tradicional.

Dins d'aquest projecte s'ha dissenyat un recipient per obtenir mostres d'aigua de 500 ml de volum; i el hardware i software necessaris per controlar el sistema de forma remota des d'un dispositiu mòbil, utilitzant un microcontrolador connectat a la nau.

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ACRONYMS

ARM Advanced RISC Machine

BOD Biological Oxygen Demand

CESE College of Environmental Science and Engineering

COD Chemical Oxygen Demand

CPU Central Processing Unit

DC Direct Current

DO Dissolved Oxygen

FPU Floating-Point Unit

GNSS Global Navigation Satellite System

PCB Printed Circuit Board

RISC Reduced Instruction Set Computing

TN Total Nitrogen

TP Total Phosphorus

TTL Transistor-Transistor Logic

UAV Unmanned Aerial Vehicles

USART Universal Synchronous/Asynchronous Receiver-Transmitter

VOC Volatile Organic Compound

WHO World Health Organization

WTP Water Treatment Plant

1. INTRODUCTION

This project has been developed in collaboration with the College of Environmental Science and Engineering, Tongji University, and the following parts in this chapter have been developed according to their specifications.

1.1. AIM AND OBJECTIVES

The aim of this project is to develop a system using UAV technology which main function is to take samples of water from drinking water sources for analysing them in a laboratory.

The following items describe the main objectives of the project:

- Study the present situation about water sampling technologies and similar solutions using UAV technologies.
- Design a water sampler able to take samples from drinking water sources up to 3 meters depth from the surface.
- Design the hardware need to control the sampler remotely.
- Program software to control the UAV and the sampler system incorporated, from an external device.

1.2. PURPOSE

It is necessary to collect data to assess the quality of drinking water resources. There are many pollutants which are harmful for human health and needed to detected and controlled before the water treatment. Depending on the water contents and its quality, the pre-treatment and treatment before it is supplied for drinking and for a human use can be different. As the WHO explains in the Guidelines for drinking-water quality, "before a new source of drinking-water supply is selected, it is important to ensure that: (1) the quality of the water is satisfactory or can be improved by treatment to make it suitable for drinking; (2) the source will yield enough water to meet the needs of the community not only under the normal conditions of the average annual cycle but also under conditions which are unusual but can be expected, say, once in 10 years; (3) under normal abstraction conditions, the change in local water flow patterns will not cause any unacceptable deterioration in the quality of the water abstracted; and (4) the water to be abstracted can be protected against pollution" [1]. For these reasons it's important to analyse drinking water quality frequently.

So far, the most common way for sampling water from surface has been from the shore of the water surface or from a boat, using the suitable equipment depending on the samples to take. Due to the expenses of time and resources, and the restrictions that these methodologies imply, this project has the purpose of reducing all those limitations and reduces the cost of water sampling developing an UAV able to perform this task.

After taking the samples, the water should be analysed in a laboratory after few hours of being taken [2]. Nevertheless, there are some parameters (turbidity, temperature, chlorophyll…) needed to assess water quality which can be determined by remote sensing techniques using optical and thermal sensors [3].

1.3. SCOPE

The aircraft has been provided by CESE and its design is not included in the scope. An enumeration of the items considered to be within the scope of this project follows:

- Study similar solutions for water sampling using UAV technology.
- Design and manufacturing of the sampler.
- Design and development of the system to take the samples from the aircraft.
- Development of the software needed to control the sampling system in the UAV remotely.
- Study some future applications for monitoring water using UAV technology.

1.4. SPECIFICATIONS

We must differentiate between the specifications for the water sampler and the restrictions given by the UAV.

There are three specifications that the sampler must meet: it should collect at least 500ml of water in each sample; the water must be able to be collected at different depths, up to 3 meters; the sampler must be made of materials which don't contaminate the water sample.

As for the restrictions given by the UAV, table 1 shows some parameters to determine them. The aircraft is a DJI model Matrice 100, and the specifications of the UAV are provided by the manufacturer.

Table 1: Specifications of the aircraft Matrice 100.

Structure	
Diagonal Wheelbase	650 mm
Weight (with battery)	2431 g
Max Take-off Weight	3600 g
Expansion Bay Weight	45 g
Battery Compartment Weight	160 g
Gimbal and Camera Weight	247 g
Performance	
Hovering Accuracy	Vertical 0,5 m; Horizontal: 2,5 m
Max Angular Velocity	Pitch: 300º/s; Yaw: 150º/s
Max Pitch Angle	35º
Max Speed of Ascent	5 m/s
Max Speed of Descent	4 m/s
Max Wind Resistance	10 m/s
Max Speed	17 m/s
Hovering Time[1]	No payload: 28 min; 1kg payload: 16 min
Operating Temperature	-10 to 40ºC
Charger	
Voltage Output	26,3 V
Power Rating	100 W
Battery	
Capacity	4500 mAh
Voltage	22,2 V
Type	LiPo 6S High voltage battery
Energy	99,9 Wh
Net Weight	600g
Operating Temperature	-10 to 40ºC
Charging Temperature	0 to 40ºC
Max Charging Power	180 W

Within the specifications above there are some restrictive parameters which are important to take into account for the design. These parameters are listed below:

[1] Hovering time based on flying at 10 m above sea level in a no-wind environment and landing with 10% battery level.

- The most restrictive parameter is max take-off weight. The maximum take-off weight is 3600g, and the aircraft itself weighs 2431g. To this weight should be added the battery compartment (160g) and the expansion bay (45g). Then, the maximum weight that can be added to the aircraft is:

$$W = 3600 - (2431 + 160 + 45) = 964\ g \quad (1)$$

  If the camera is added, the maximum weight will be:

$$W = 964 - 247 = 717g \quad (2)$$

  This maximum weight will be taken into account during all the design and cannot be exceeded.
- Hovering time is a very important parameter. It is the maximum time the aircraft can be hovering, the time from the take off to the landing. As the aircraft will have a load up to 1 kg (up to 500 g without the sample of water), the hovering time taken into account is the time with 1 kg payload: 16 min.
- Some other performance parameters (max speed, speed of ascent and descent, max angular velocity, max pitch angle) are important when programming missions and during flights.
- Operating temperature and max wind resistance are parameters related with weather and will be a restriction when flying the UAV under weather situations which exceed the maximum values.

The drawing of the drone assembled is illustrated in figure 1.

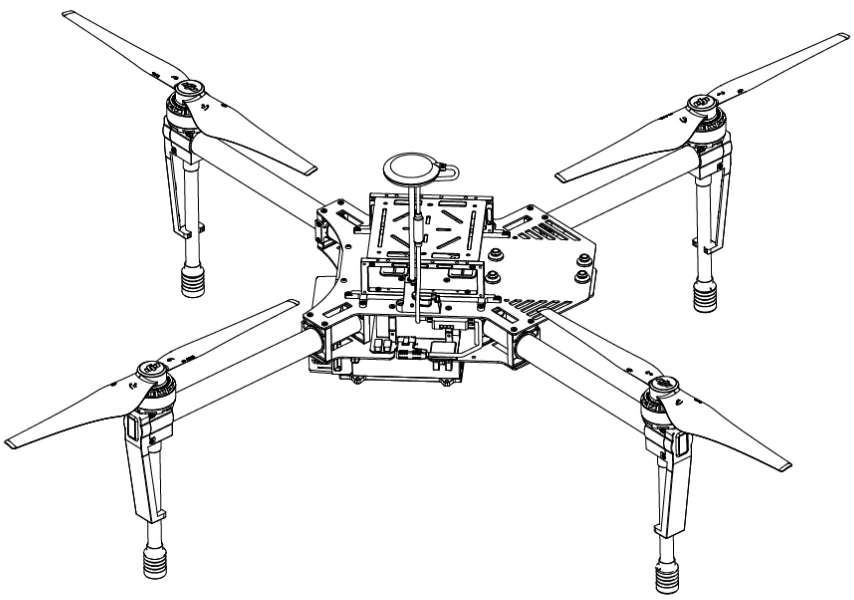

Figure 1. Drawing of the assembled DJI drone, model Matrice 100.
Source: https://www.dji.com/es/matrice100

2. STATE OF THE ART

2.1. TAIHU LAKE CASE STUDY

With a catchment area of 36.500 km^2, Taihu Lake is the second largest freshwater lake in China. It is located in Yangtze delta, in the eastern China, and it is a drink water source for many cities around it (see figure 2). It has a water surface of approximately 2.338 km^2 and an average water depth of 1,9 m [4].

Figure 2. Taihu Lake location in eastern China.
Source: www.jiangsu.net/map/regions/laketaihu.php

Description of the problem

At present, there are some lakes all over the world with eutrophication problem and algal bloom. Eutrophication is considered as the key factor of water quality degradation. Eutrophic lakes always carry too many nutrients that lead to algal blooms. The water quality in Taihu Lake has been deteriorating these years and the lake is in a highly eutrophication level now. Algal blooms, particularly blue-green algal, become the most troublesome problem. They take place every summer and seriously threaten the drinking water safety in the Taihu Lake basin (see figure 3).

Figure 3. Blue-green algal blooms in Taihu Lake.
Source: https://www.chinadialogue.net/article/1082-Disaster-in-Taihu-Lake

The most serious water event happened in Jiangsu in recent years may be the water crisis in the year 2007. The water crisis swept Wuxi city in a sudden. Two millions of people had a shortage of clean drinking water for almost one week. On 16th May, the water from the intake of Meiliang Bay started to get turbid and smelt badly. The Xiaowanli water treatment plant stopped supplying water due to the bad water quality. It was investigated that large number of blue-green algae around the water intake of Xiaowanli WTP died and get rotted rapidly. According to a report from the related department on 28th May 2007, water quality from Gonghu WTP was really bad, the ammonia nitrogen index went up to 5 mg/l while DO (dissolved oxygen) down to 0 mg/l. Three days later, the ammonia nitrogen index was still 6.55mg/l high, and DO went back to 0.33mg/l [5].

During the first few days of the water crisis, the tap water in the urban area looked swampy. Certainly, it was not portable even after being boiled. Panic buying for bottled water happened and nearly cleared the shelves in every store. In the following days, the tap water still smelt really badly but became less swampy because of the chemicals adding into it. Though the tap water was not as turbid as before, people were not able to drink it, have shower or cook with it. Citizens in Wuxi were really worried and anxious to know when they could have safe and clean drinking water again.

A large volume of water was transferred into Tai Lake from the Yangtze River to dilute the high algal concentration. Other measures like water diversion from Meiliang Lake were also carried out. To rehabilitate the water supply as soon as possible, experts came across the country to deal with the problem. Though the tap water was no longer turbid, bad smell from chemicals added to get rid of algae still left. Nobody can drink that kind of water trustingly.

Solution of the problem

It was launched the integrated water management project in the Tai Lake watershed by the Jiangsu provincial government in December 2007, after blue-algae accident.

In this project, the provincial government sets two sets of objectives, including the pollutants discharge objectives and the water quality objectives. The former set of objectives includes the COD, ammoniate, total phosphor and total nitrogen indicators. The latter two ones are most recent indicators, in the past the government mostly focused on the COD, but now they also concern the phosphor and nitrogen indicators, since they are key factors to cause blue algae proliferation.

Moreover, strict discharge standards, including COD, NH3-N, TN, TP and water use, were implemented in some industries as wastewater treatment plants, chemical, papermaking, steel, electroplating and food manufacturing. Also, stricter access standards were regulated. Besides, the enterprises with out-of-date technologies would be closed. Industrial structures had to be optimized and traditional industries such as chemical, printing and dyeing were adjusted. At the same time, the high-tech industries were supported and developed and the tertiary industries greatly improved.

In May 2008, China allocated more than 111 billion yuan to a plan to improve the lake's water quality from "class V" – the dirtiest category – to "class IV", and in places "class III", by 2020. But the issue remains serious. On November 1 2013, China's vice minister for water resources Li Guoying admitted that water quality at over 60% of water supply points in the Tai Lake Basin is below "class III".

The combination of pollution, water scarcity and flood-prevention considerations have forced Tai Lake to turn to the Yangtze River for help. In 2001, the central government called for large quantities of Yangtze water to be moved to the lake in a bid to improve water quality. Trial water diversions got underway in early 2002.

The project used an existing channel – the Wangyu River – to transfer the water. The idea was to get the water in the lake moving, increasing downstream flow and boosting the ability of the bodies of water in the Tai Lek Basin to cleanse them.

The Wangyu River flows along the border between Wuxi and Suzhou. In the north, it connects to the Yangtze at Gengjingkou then flows through the lakes of Jialingdang and Caohu before reaching Tai Lake at Shadunkou. It is 60.8 kilometres long [6].

From this case study, it is intended to use the drone to take samples of water and monitor water parameters in a more economic, easier and faster way than the traditional way that is being used nowadays. If it works for this case, it can be used for other similar places were water sources suffer the same problem, with high presence of this kind of cyanobacteria, or any other pollutants harmful for human health.

2.2. WATER SAMPLING TECHNIQUES

There is much different equipment for water sampling. First of all, it must be differentiated surface-water and ground-water; in this project only surface-water equipment will be taken into account. It is also important the chemical nature of the target analyte. Other important aspects to determine which equipment to use for sample collection are the study objectives, the depth at which the samples will be taken, the flow conditions and the structure from where the sampler will be deployed [7] (in this case the structure will be the UAV).

Samples of water for determining trace elements can contact only non-contaminating materials such as fluorocarbon polymer and polypropylene. When the samples are for determination of organic compounds different non-contaminating materials are used: typically metals (stainless steel), fluoropolymers (Teflon®) or ceramics (microcrystalline alumina).

Isokinetic depth-integrating samplers

This equipment is designed to accumulate a representative water sample continuously and when the stream water surrounding and entering the sampler does not change in velocity. These samplers are classified into two groups according the suspension method: hand-held samplers and cable-and-reel samplers. Hand-held samplers are used when the target water surface can be waded or where a bridge or a structure is accessible and low enough from the water surface to take the sample. Isokinetic samplers are illustrated on figure 4.

For collecting an isokinetic sample it’s important to know the stream velocity, which usually must be greater than 0,5 m/s.

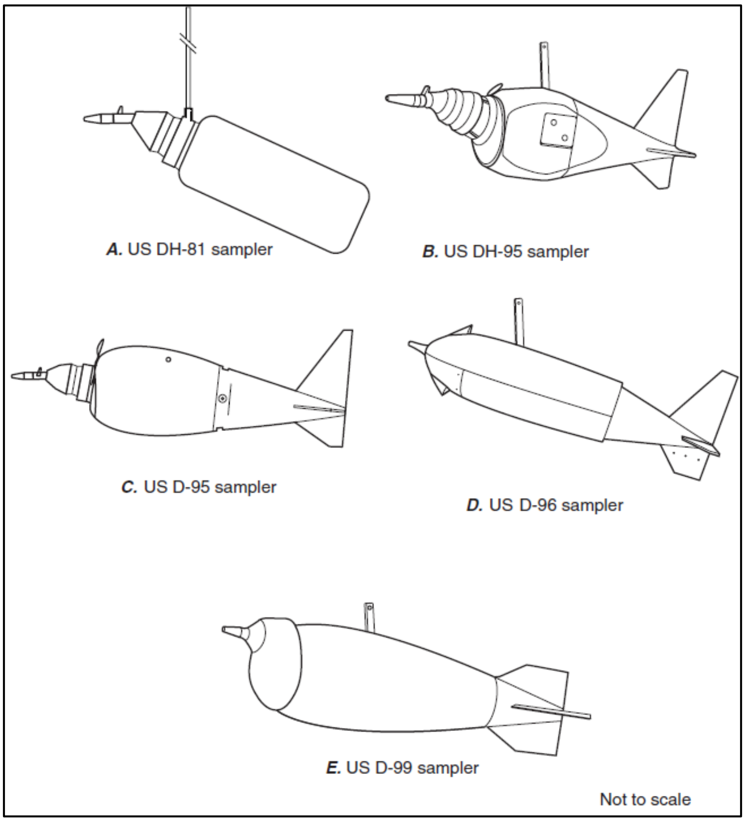

Figure 4. Isokinetic depth-integrating samplers.
Source: National Field Manual for the Collection of Water-Quality Data. *U.S. Geological Survey.*

US DH-81 (figure 4 A) and US DH-95 (figure 4 B) are both hand-held samplers. They can be used for both inorganic and organic samples, and always when the water surface can be waded or accessible from another structure.

US D-95 (figure 4 C), US D-96 (figure 4 D) and US D-99 (figure 4 E) are cable-and-reel samplers, used when flowing water shouldn't be waded. Same as hand-held samplers, these can be used for both inorganic and organic samples.

Non-isokinetic samplers

This kind of samplers is used when the sample enters the device at a velocity that differs from ambient stream velocity. There are different kinds of non-isokinetic samplers depending on where the samples are taken from: open-mouth samplers, thief samplers, single stage samplers and automatic samplers.

Open-mouth samplers, illustrated in figure 5 are those with a bottle with one side opened. They are all used for low flow velocities.

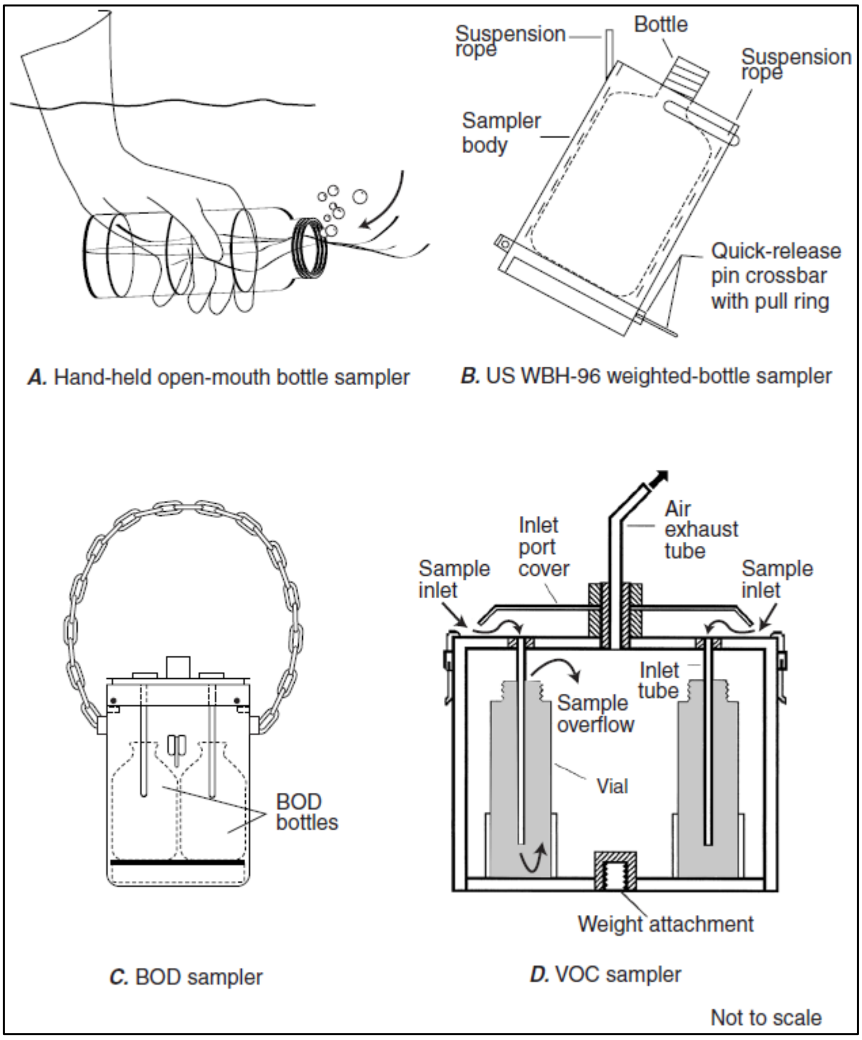

Figure 5. Non-isokinetic open-mouth samplers.
Source: National Field Manual for the Collection of Water-Quality Data. *U.S. Geological Survey.*

Hand-held open-mouth bottle sampler (figure 5 A) is the simplest type, used to collect samples where depth and velocity are very low. US WBH-96 sampler (figure 5 B) is used when flow velocity is low but for deeper water, when the surface cannot be waded; the sampling depth is restricted by the capacity and rate of filling of the bottle. BOD and VOC samplers (figure 5 C-D) are used to collect non-aerated samples.

Thief samples are used for instantaneous discrete samples. They are proper to collect water from lakes, reservoirs and estuaries. The most commonly used are shown in figure 6.

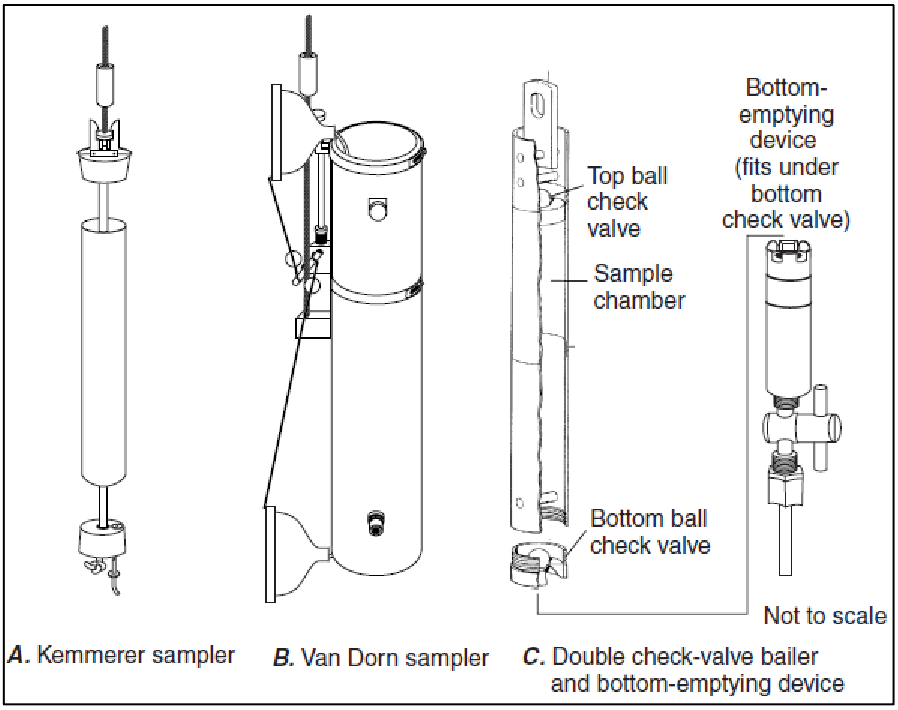

Figure 6. Non-isokinetic thief samplers.
Source: National Field Manual for the Collection of Water-Quality Data. *U.S. Geological Survey.*

Single-stage samplers are designed to collect suspended sediment samples from streams where rapid changes make it difficult to use an isokinetic sampler. They can be set up above each other to collect samples from different depths and times. A single-stage sampler, US U-59, is illustrated in figure 7.

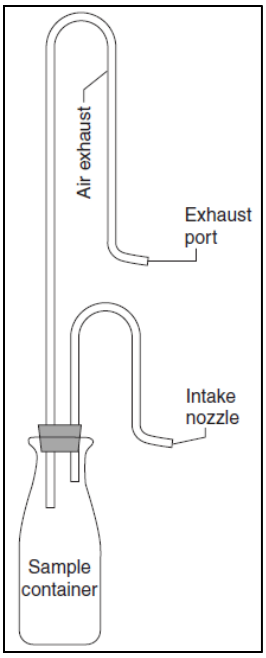

Figure 7. Single-stage sampler US U-59.
Source: National Field Manual for the Collection of Water-Quality Data. *U.S. Geological Survey.*

Automatic samplers are usually used to collect samples at remote sites, or when the stage rises quickly. They used a pump to drain water and can be programmed at preset time intervals or selected stages. They are considered pint-integrated samples [7].

2.3. UAV APPLICATIONS

Drone technology was developed, at first, for military applications [8], but nowadays it is also used for environmental research with very diverse applications. Nonetheless its use for water sampling is not overly common. There are some water sampling solutions using UAV technology, but most of them exceed the load weight restriction of the aircraft used in this project. In this section some of these solutions are summarized.

Autonomous Aerial Water Sampling

This autonomous aerial water sampling drone was developed at University of Nebraska [9]. They developed a system to collect water samples faster, less expensive and which requires less effort than the traditional methods. This system collects three different samples of 20 ml. The water to collect is pumped into the containers, which are attached to the drone, as can be seen in figure 8. This method has a limitation; it can only collect water from the surface because of the pump usage. The design of the collector is 3D printed, so it guarantees no cross contamination between the water samples. It also has a sensor system to control the altitude over water to know how to collect the samples and for a safe navigation.

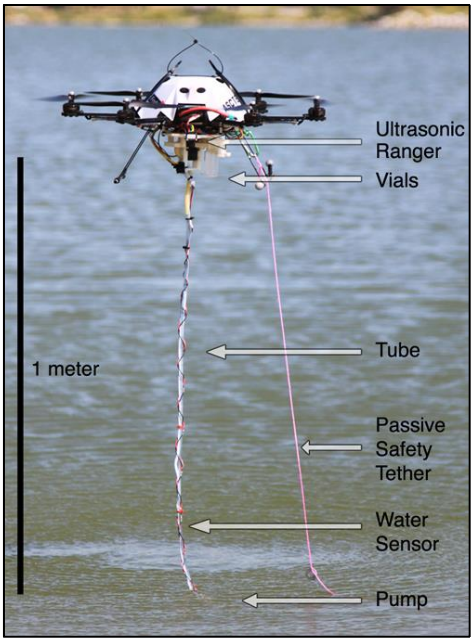

Figure 8. Autonomous Aerial Water Sampling.
Source: J.-P. Ore, S. Elbaum, A. Burgin, B. Zhao and C. Detweiler, "Autonomous Aerial Water Sampling," Journal of Field Robotics, *vol. 32, pp. 1095-1113, 2015.*

The Lusi drone

The Lusi drone is a multi-purpose UAV capable to complete different tasks (i.e. video survey, aero photography, monitoring and sampling) designed for the harsh environment of the Lumpur Sidoarjo mud volcano, Indonesia [10]. It is equipped with an infra-red camera to locate areas with higher heat flux and know the deep fluids rise ways. It can also log temperature and pressure at a specified point or transmit continuous measurements parachuting the loggers. Its gas sensors can draw maps of gas distribution, while gas samples can collect it. The drone also collect liquid and solid samples from non-accessible sites using a Teflon® sampler connected to an automatic winch, which is shown in figure 9.

Figure 9. Lusi drone sampler connected to the winch.
Source: G. Di Stefano, G. Romeo, A. Mazzini, A. Iarocci, S. Hadi and S. Pelphrey, "The Lusi drone: A multidisciplinary tool to access extreme environments," Marine and Petroleum Geology, *vol. 90, pp. 26-37, 2018.*

Water sampling at Yugama Crater Lake

This study uses a drone to sample lake water from Yugama crater lake, Japan [11]. It is used a six-rotor drone with a flight autonomy of 40 min, with two batteries of 350 Wh and a total weight of 4 kg and it can take off with a maximum load of 12 kg. Although an operator should control the aircraft during takeoff and landing, it can navigate automatically by GNSS. The sampling device, illustrated in figure 10, consists on a bottle made of high-density polyethylene which has a hollow tube-like structure to allow water flow up through the tube when it is lowed into the lake. It uses two balls to stop the downward flow when the bottle is pulled upwards. The bottle has a weight of 0,115 kg and can sample a maximum of 330 ml of water. The bottle is suspended from a 30 m length rope, and it has 3 weights of 200 g disposed at different distances to prevent it from being disturbed by wind.

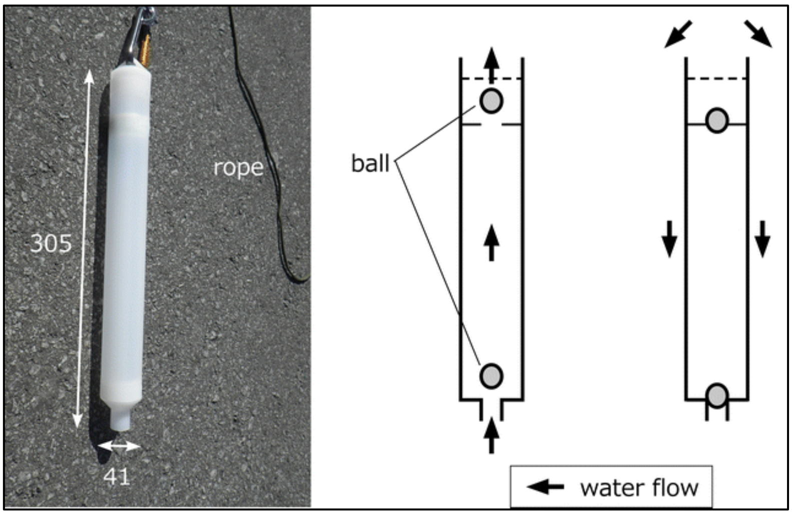

Figure 10. Photograph and illustration of the water sampling bottle, Yugama Crater lake sampler. Source: A. Terada and T. H. T. M. Yuichi Morita, "Water sampling using a drone at Yugama crater lake, Kusatsu-Shirane volcano, Japan," Earth, Planets and Space, *2018.*

3. DESIGN

3.1. WATER SAMPLER

This project has been developed thinking about Taihu Lake case study and the presence of cyanobacteria on that lake. Therefore, the main purpose will be to collect samples from reservoirs and lakes. For this reason, to design and develop the water sampler the thief samplers are the most suitable.

Nowadays the most used is the Van Dorn sampler, but in this project one of the main restrictions is the maximum load the UAV can support, and the need of a messenger to close the sampler increase considerably the load. For this reason the final design is a simpler and lighter sampler inspired on the existing samplers studied before.

Structure

The sampler is formed by a container with 0,5l capacity, a check valve on the bottom and a small overture on the top to permit the filling and which can be used for the emptying by the use of a stopcock. Figure 11 shows the final design of the sampler.

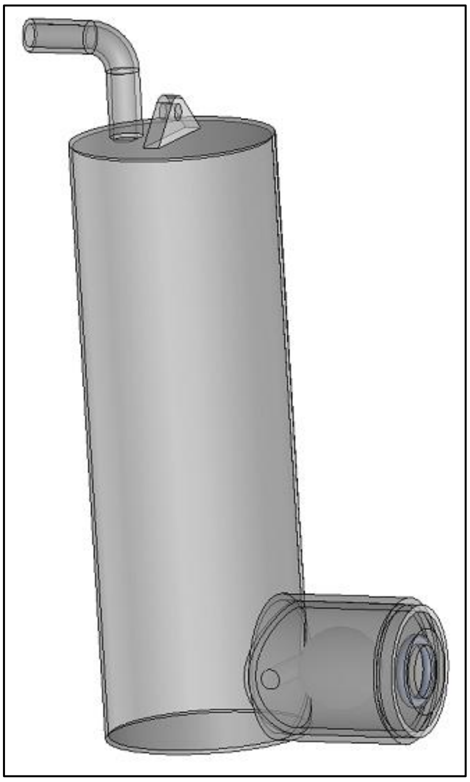

Figure 11. 3D design of the water sampler.
Source: Own work.

The first step is to design the system by which the sampler will collect the water, and the best solution to allow water to enter the container and prevent it from going out is a check valve. There are different types of check valves: swing type (top hinged and tilting disk), lift type (piston and ball types), dual plate type and stop check valve. Stop check valve are not considered for this application; the best options could be ball type, swing type and dual plate type. To select one of these check valve types it has been considered to reduce the mechanisms, joints and bearings, since these parts are prone to attrition. Therefore, the best solution is the ball type check valve. And to simplify the system, it consists on a 25mm diameter rubber ball, and an O-ring with 16mm inner diameter and 22mm outer diameter, to seal the water flow. Figure 12 shows the 3D model of the check valve designed.

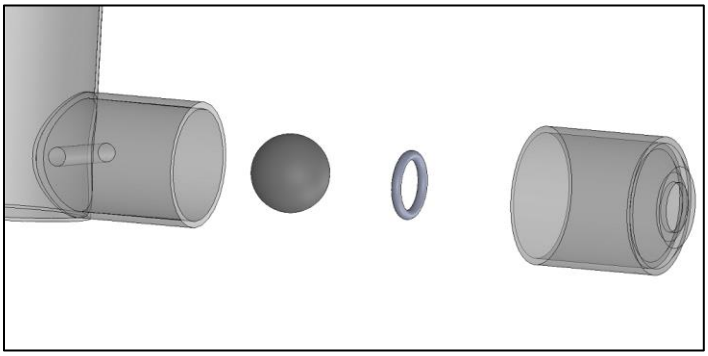

Figure 12. 3D design of the ball type check valve.
Source: Own work.

According to the project specifications the minimum volume for the water samples required is 500ml, so the sampler capacity must be equal or greater than this value. To determine the dimensions of the bottle, it has started from a base diameter of 60mm. Then, to calculate the height of the bottle:

$$V = \pi \times R^2 \times h; \quad (1)$$

$$500 = \pi \times 3^2 \times h; \quad (2)$$

$$h = \frac{500}{\pi \times 3^2} = 17{,}68\ cm \quad (3)$$

The height of the bottle (equation 3) must be above 17,68cm. So, rounding up, the height selected is 18cm.

The sampler is controlled from the UAV using a microcontroller, which is connected to a DC motor to ascend and descend the sampler to the desired height using a rope. The connections, design and programming of this part is described on the next section.

Material

To choose the material for the sampler there are some restrictions to take into account:

- The sampler must be made of a material which doesn't pollute the water inside, not dissolving any kind of substances that can vary the results when the water is analysed.
- When choosing the material the weight should be taken into account, as the maximum load the drone can support is one of the main restrictions. Even with a weight within the limits, the lighter the load, the higher the flight time will be.
- This prototype will be produced using a 3D printer, so the material must be compatible with this technology.

There are some materials which can be used for 3D print, but not all of them are compatible with the sampler, as some of them may contaminate the water inside. In table 2 are listed some of the compatible materials and their characteristics.

Table 2. Characteristics of some possible materials for the water sampler

Material	Density (g/cm^3)	Durability	Difficulty to use	Soluble	Comments
Polylactic Acid (**PLA**)	1,24	Medium	Low	No	It's a very useful material for 3D printing for its ease to be treated. The inconvenient is that it is brittle compared with other materials, so it won't be a good choice if the sampler may be hit when the drone lands.
Acrlylonitrile Butadiene Styrene (**ABS**)	1,04	High	Medium	In esters, ketones and acetone	It has high durability and able to withstand high stress, and moderately flexible. It is useful for those items frequently handled and dropped, so it's a good option for the sampler.
Polyethylene Terephthalate (**PET**)	1,27	High	Medium	No	It has a high durability, flexibility, strength and impact resistance. It is the most used plastic, known for its use in water bottles, so it's a very good choice for the water sampler.

Polypropylene (**PP**)	0,90	High	High	No	It is tough, flexible, light, chemically resistant and food safe, so it has a huge range of applications in many different fields, including packaging for consumables and medicines, and laboratory material. It is also very light, so it would be the perfect option for the sampler, but unfortunately it is very difficult to use for 3D printing, so it is not a good choice.

Note: Data from All3DP, "3D Printer Filament Guide – All You Need to Know in 2019," 2019. [Online]. Available: https://all3dp.com/1/3d-printer-filament-types-3d-printing-3d-filament/

Among the materials listed in the table above, the best option would be PP for its properties, besides the ease of being recycled and turn it into new 3D printer filament. Even so, due to its difficulty to be printed it is not frequently used and may be expensive to process. [12]

Then, there are three options to choose, and the one which fits better the needs for the sampler is the PET. It's heavier than ABS, but the difference, for the volume used in the sampler, it is not a big deal, and this weight may be useful for let the water in when the sampler reach the water surface. It is widely used for water bottles manufacture so it's a good option for the sampler. Additionally, it can be recycled easily for other uses.

3.2. ELECTRONIC SYSTEM

The water sampler will be controlled remotely using an app from an Android device. The app will control the height of the sampler using a rope, attached to the sampler and a DC motor, which will be connected to a winch and make it rotate to lengthen or shorten the rope.

It is need an electronic system to receive data from the Android device and activate the motor. Figure 13 shows the structure and connections between all the electronic components needed to control the system.

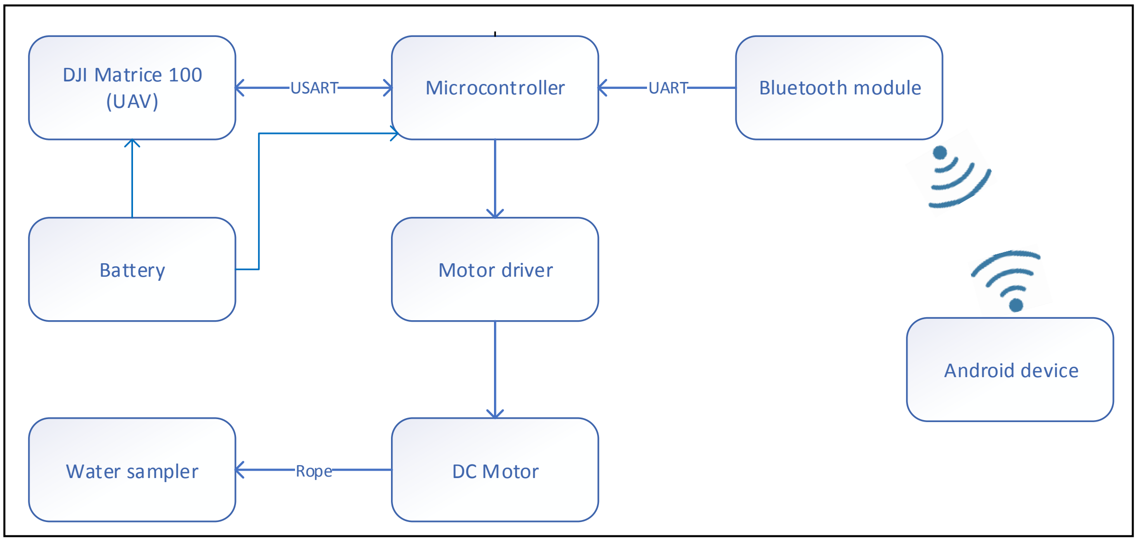

Figure 13. Schematic connections for the sampler system.
Source: Own work.

The drone will be connected by USART communication to the microcontroller, and the same battery which supplies power to the drone will supply power to the microcontroller. The microcontroller will receive data from the android device through Bluetooth communication, and by the use of a motor driver will run the DC motor to move the water sampler.

Components

Microcontroller

To control the water sampler and the drone it is need a microcontroller connected to the drone and the motor. The embedded system recommended by DJI is STM32, F4 Discovery Series. Among all the options given by STM, the most economic board that fits best the needs of the project is STM32F407VG Discovery. Figure 14 shows the board from both sides. This board is a cheap solution which solve all the project needs.

To program the board, it is only need: as hardware, a USB A to min-B cable, and a PC with USB entry; about the software, it is need a Windows OS, and a developing software for microcontrollers, like Keil, Atollic or IAR.

A) B)

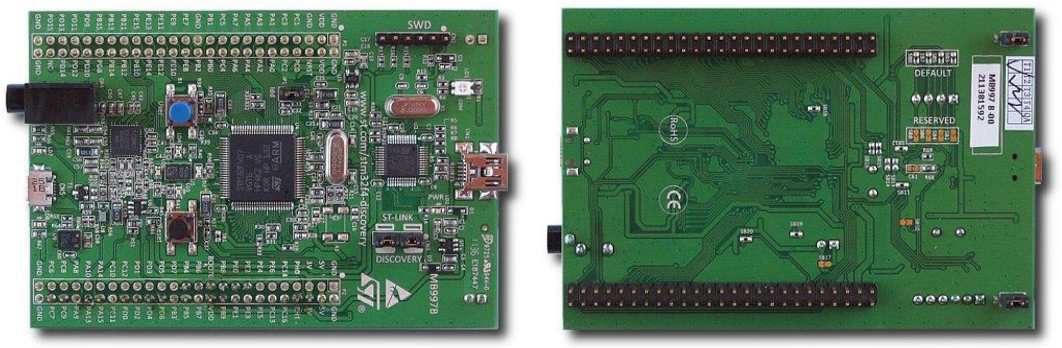

*Figure 14. STM32F407VG microcontroller picture. A) Top side; B) Bottom side.
Source: https://www.st.com/en/evaluation-tools/stm32f4discovery.html*

Characteristics:

- Core: ARM®32-bit Cortex®-M4 CPU with FPU, frequency up to 168 MHz, memory protection unit
- Up to 1 Mbyte Flash memory
- Up to 192+4 Kbytes of SRAM including 64-Kbyte of CCM (core coupled memory) data RAM
- Flexible static memory controller supporting Compact Flash, SRAM, PSRAM, NOR and NAND memories
- 1,8 to 3,6V for power supply from one single source
- 50 I / O multiplexed pins with different peripherals inside
- Ethernet connection

Other devices and peripherals:

The board has four LED diodes and a pressing switch which can be programmed by the user for different applications. It has 50 I / O pins, 25 in each side, all of them male connectors.

<u>DC Motor</u>

There is a DC motor to control the height of the sampler, by a winch and a rope usage. The motor power is supplied by the microcontroller, using a motor driver. To choose the motor, it must be calculated the minimum torque needed to raise the sampler full of water.

The sampler weight plus the water inside may be from 500 to 600 g. The torque needed to raise the sampler depends on the diameter of the winch, which may be 1 or 2 cm. To calculate the torque needed the weight and the winch radius distance are multiplied. This means that the torque may be from 0,25 to 0,5 kg·cm.

The gearmotor chosen (see figure 15) has a nominal torque of 0,5 kg·cm, so the diameter of the winch will be chosen according this number, then it will be less than 2 cm.

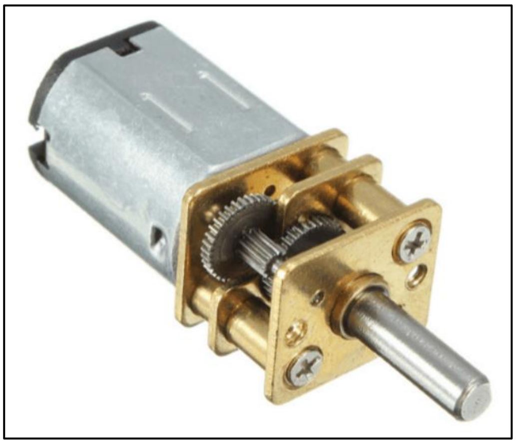

Figure 15. Gearmotor chosen for moving the sampler.
Source: Own work.

The gears are needed to reduce the speed of the motor, increasing the torque. For this project, the speed should be low, and it is more important the torque required to raise the sampler, so it is very important the use of this gears. It consists on a gear train with a transmission rate of 1:298.

Characteristics:

- DC input voltage: 3V
- Reduction rate: 1:298
- Rotating speed: 25 rpm at a nominal voltage
- Nominal torque: 0,50 kg·cm
- Current: 60mA; maximum current: 100mA

<u>Motor driver</u>

To control and supply power to the DC motor it is needed a motor driver. It is connected between the board and the motor. The motor driver chosen is L298N by ST.

The L298N is an integrated monolithic circuit in a 15-lead Multiwatt and PowerSO20 packages. It is a high voltage, high current dual full-bridge driver designed to accept standard TTL logic levels and drive inductive loads such as relays, solenoids, DC and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The emitters of the lower transistors of each bridge are connected together and the corresponding external terminal can be used for the connection of an external sensing resistor. An additional supply input is provided so that the logic works at a lower voltage [9].

Figure 16 shows the PCB from the top side and schematic diagram are illustrated in figure 17.

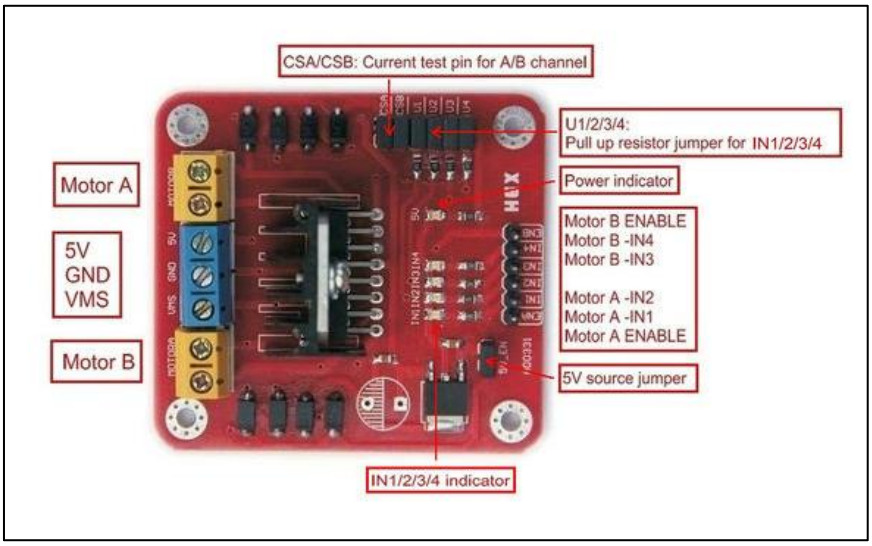

Figure 16. L298N top side with connections detail.
Source: https://www.st.com/en/motor-drivers/l298.html

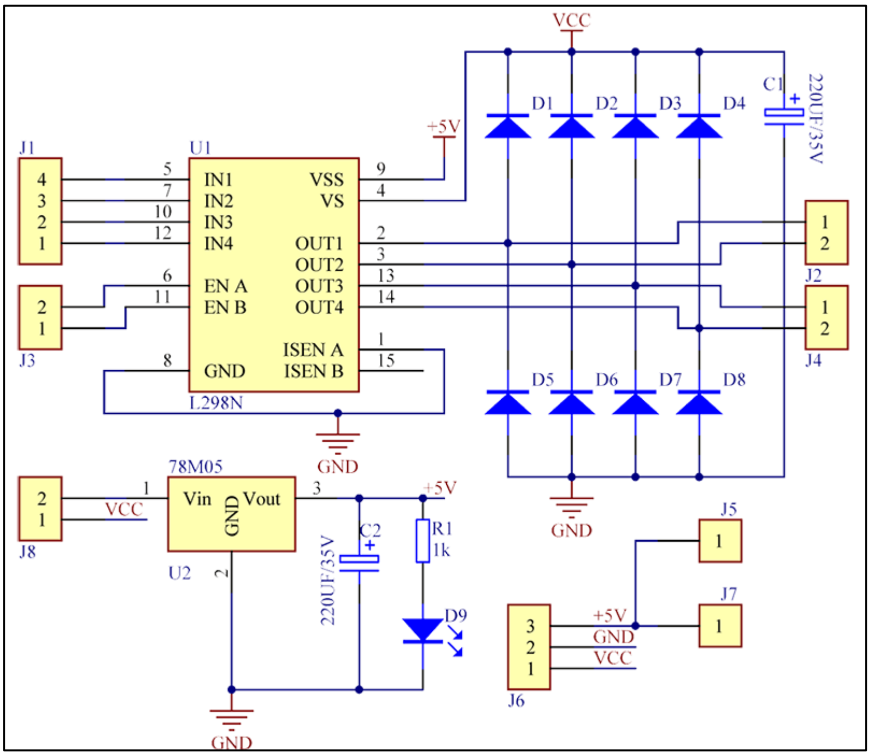

Figure 17. L298N schematic diagram.
Source: https://www.st.com/en/motor-drivers/l298.html

Characteristics:

- High operating voltage, which can be up to 40 volts;
- Large output current, the instantaneous peak current can be up to 3A;
- With 25W rated power;
- Two built in H-bridge, high voltage, large current, full bridge driver, which can be used to drive DC motors, stepper motors, relay coils and other inductive loads.
- Using standard logic level signal to control.
- Able to drive a two-phase stepper motor or four-phase stepper motor, and two-phase DC motors.
- Adopt a high-capacity filter capacitor and a freewheeling diode that protects devices in the circuit from being damaged by the reverse current of an inductive load, enhancing reliability
- The module can utilize the built-in stabilivolt tube 78M05 to obtain 5v from the power supply. But to protect the chip of the 78M05 from damage, when the drive voltage is greater than 12v, an external 5v logic supply should be used.
- Drive voltage: 5-35V; logic voltage: 5V
- PCB size: 4.2 x 4.2 cm

Bluetooth module

To establish wireless data communication between the microcontroller and the device, the microcontroller must be connected to a wireless module, which will receive the data from the device and send it to the microcontroller.

The Bluetooth module chosen is the JDY-30, shown in figure 18, and it acts as a slave, which means it only receive data, it can't send it to another device. It has 6 pins, and it is connected to the board by UART communication. In table 3 are listed the six pins with their function.

Table 3. Bluetooth module pins and their function.

Pin	Name	Function
1	Key	The pin state determines whether the module works in AT command mode or normal mode. [High=AT commands receiving mode (Commands response mode), Low or NC= Bluetooth module normally working]
2	Vcc	+5V Positive supply needs to be given to this pin for powering the module.
3	Gnd	Connect to ground.
4	TXD	The module transmits serial data through this pin (at 9600bps by default), 3,3V logic.
5	RXD	The module receives serial data through this pin (at 9600bps by default), 3,3V logic.
6	State	The pin is connected to the LED on the board to represent the state of the module.

For interfacing the module successfully, only four pins need to be connected to the board: Vcc, Gnd, TXD and RXD.

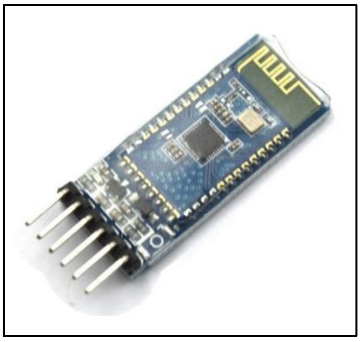

Figure 18. JDY-30 Bluetooth module.
Source: Own work.

Characteristics:

- Operating voltage: 2,2 – 4,2 V
- Operating temperature: -40ºC – 80ºC
- Antenna: PCB Onboard Antenna
- Current: Normal mode 19 mA; Sleep mode 40 °µA

Connections

The connections between the electronic components are explained from their electronic schemes. Figure 19 shows the scheme of the LQFP100 microcontroller, within the board STM32F4DISCOVERY.

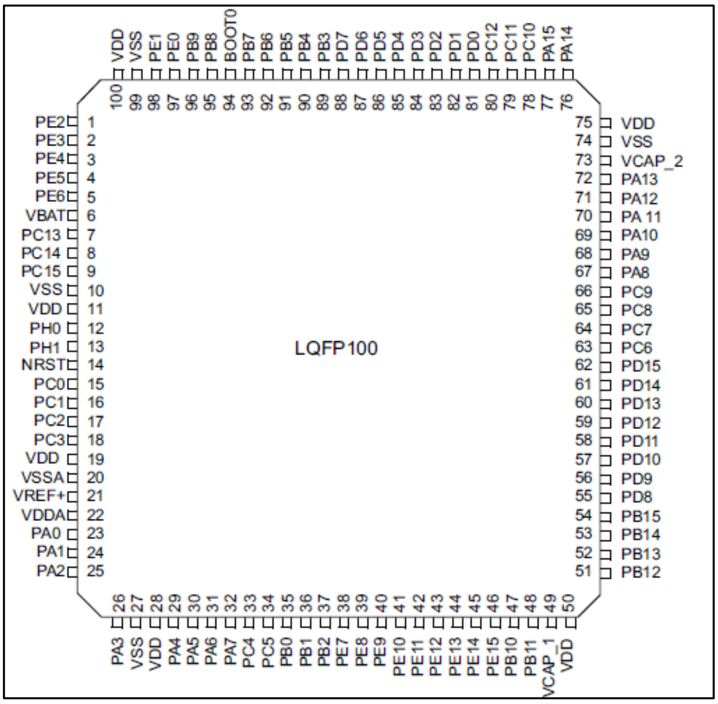

Figure 19. Microcontroller LQFP100 scheme.
Source: https://www.st.com/en/evaluation-tools/stm32f4discovery.html

First of all, to power the board, it is necessary a USB to TTL adapter (see figure 20) to connect between the board and the drone, and supply the power from the drone to the board. But to connect the board has a mini USB entry to power it, so it will be used an adapter, as the one shown in figure 21.

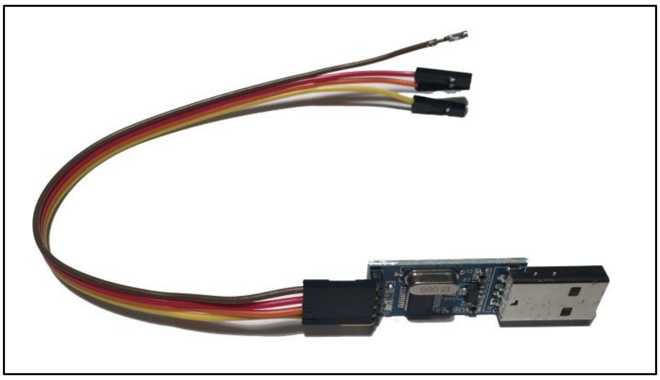

Figure 20. USB to TTL adapter.
Source: Own work.

Figure 21. USB female to mini USB male adapter
Source: https://www.fasttech.com/product/1174700-usb-female-to-mini-usb-male-adapter-cable

The TTL terminals are connected directly to the drone via UART connection, on the entries specified on the aircraft.

Then, to connect the motor to the board, the pins PD0, PD1, PD2 and PD3 on the board STM32F4 are connected to IN1, IN2, IN3 and IN4 on the motor driver L298N. Then the motor is connected to the motor A connections and the pin 5V supply from the board to VMS connection on the driver. These connections are shown on figure 22.

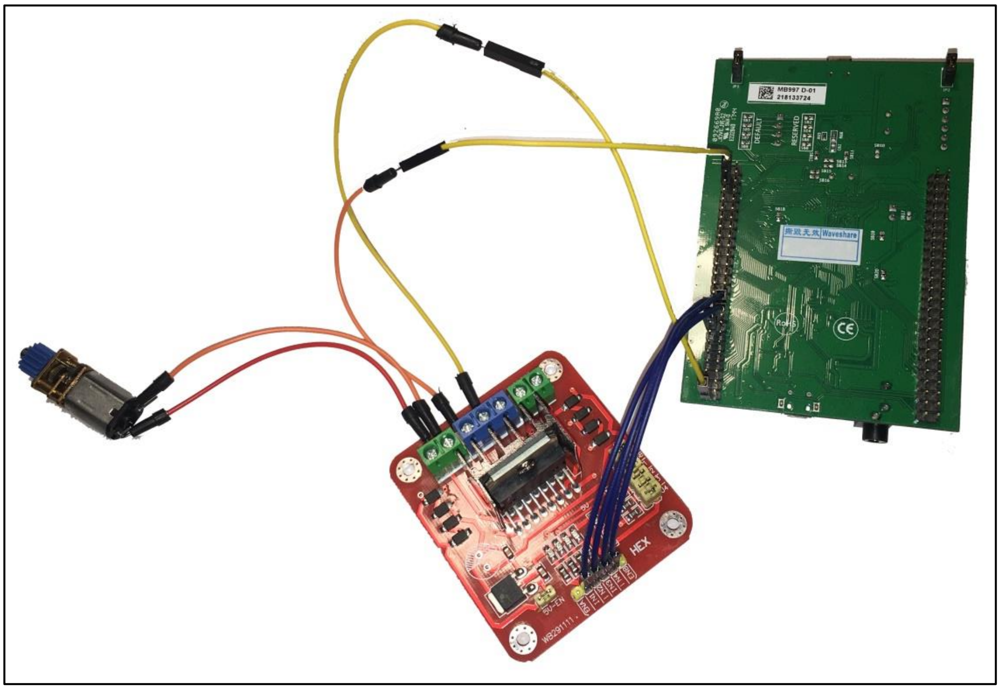

Figure 22. Connections from the board to the motor driver and the DC motor.
Source: Own work.

Finally, to connect the JDY-30 Bluetooth module the connections are via UART communication, so pins PA9 and PA10 on the board are connected to TX and RX on the Bluetooth module respectively, as illustrated on the scheme in figure 23. The real connections between the two devices are shown in figure 24.

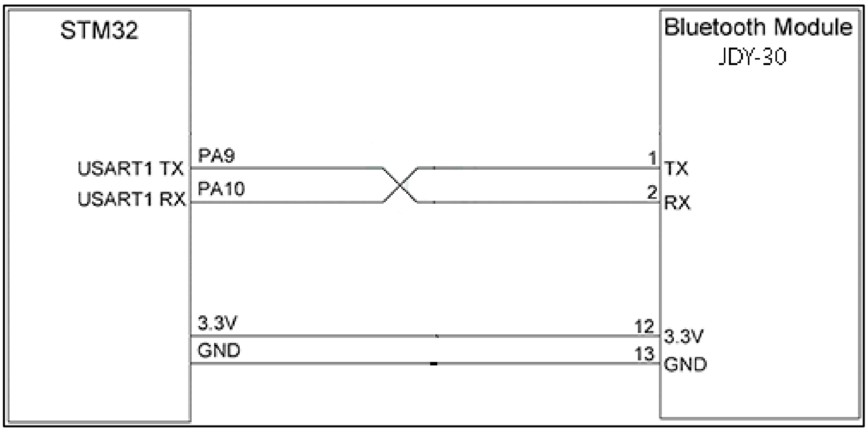

Figure 23. Schematic connections between the board STM32F4 to the Bluetooth module JDY-30.
Source: Own work.

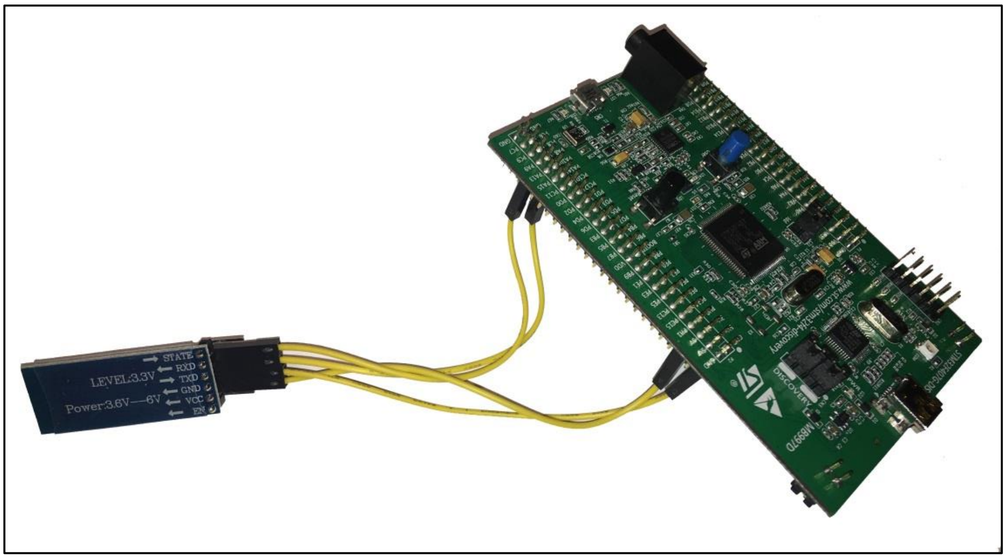

Figure 24. Connections between the board and the Bluetooth module.
Source: Own work.

Programming

The software has been programmed using Kiel µVision. To do it, first of all, the STM32F407VGT pack should be installed, as shown in figure 25.

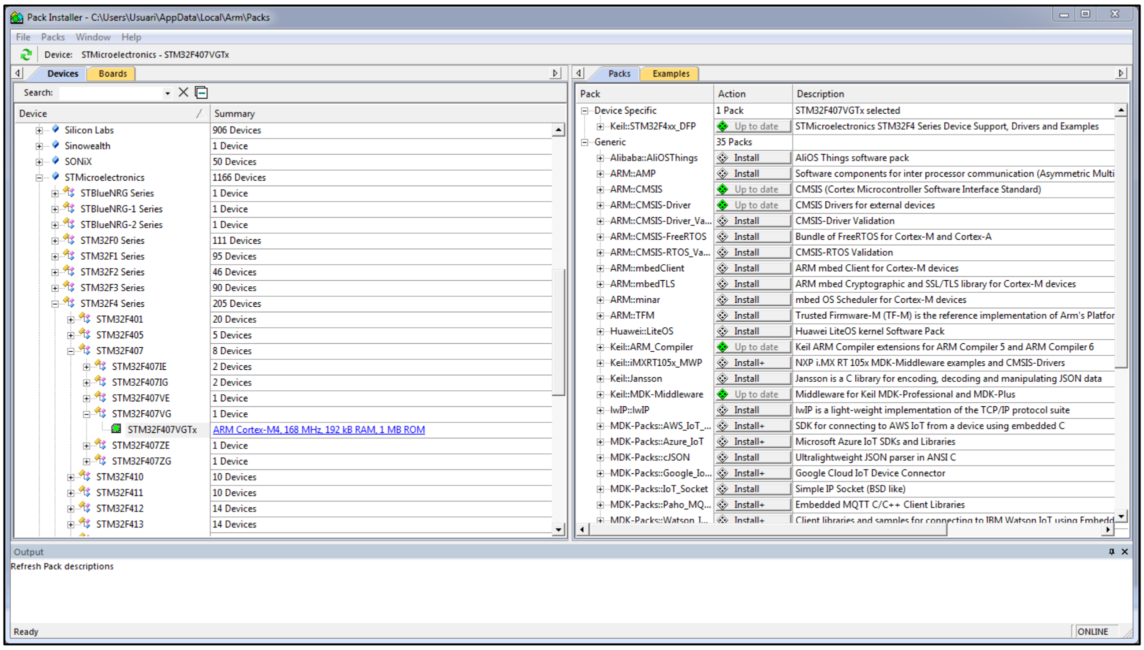

Figure 25. Installation of drivers for STM32F407VGT board.
Source: Own work.

This program will use 2 header files (“motor” and “move”) and 3 C files (“motor”, “move” and “main”), as it is shown in figure 26. All the code to use the Bluetooth module is included in the main file.

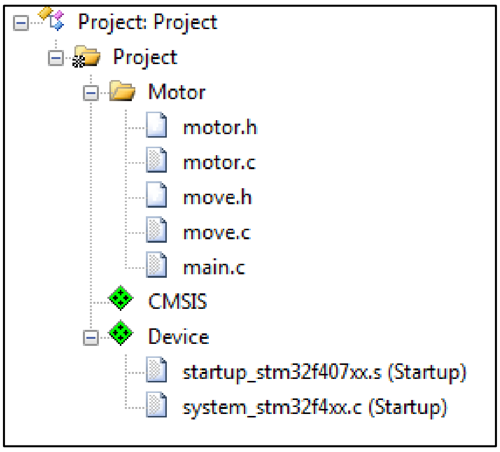

Figure 26. Scheme of the project files.
Source: Own work.

The program is debugged and built with the same software, Kiel µVision, and it is downloaded into the board connecting it to the computer. To connect the board to the computer it is used a USB to mini USB cable as shown in figure 27.

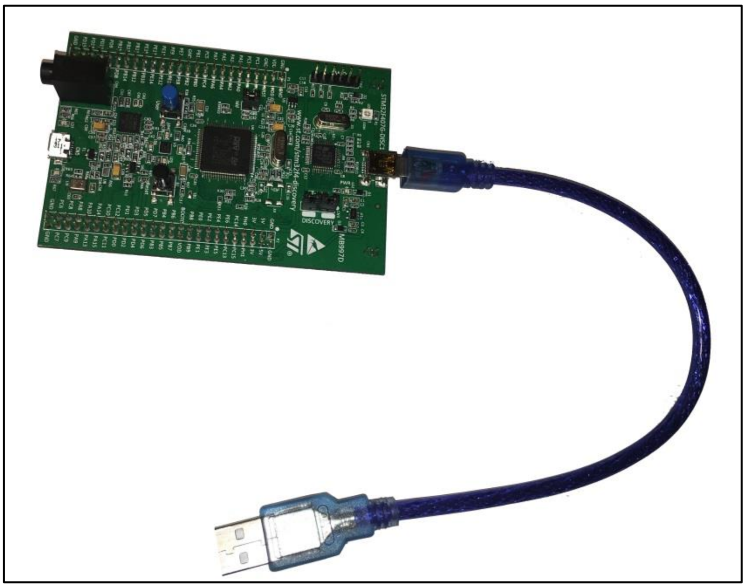

Figure 27. Connection between the board and the PC.
Source: Own work.

All the content of the program is defined in the annexes document (document II), Annex A.

4. BUDGET SUMMARY

In this section you can see a summary of the budget of this project.

The budget has been divided into four stages following the structure of this document. The detail of the costs associated with each stage can be seen in the budget document (document IV)

Table 4 shows the cost of each phase and the sum of the total cost of the study.

Table 4. Total cost of the project.

Concept	**Cost (€)**
Initial study and background	1.100,00
Design of the water sampler	1.140,60
Design of electronic system	4.638,00
Software design	1.800,00
TOTAL	8.678,60

Then, including the cost of each stage, cost of the materials and the drone, the total cost of the project is 8.678,60€.

5. ENVIRONMENTAL IMPACT

The mainspring of this project is to develop a tool to know the environmental impact of external factors in drinking water sources. It will help to assess water quality and monitor it with a reduced cost.

Nowadays, if it is needed a sample of water far from the shore and there is no structure to stand on, it is used a boat to carry all the equipment and take the samples from it, which means an important environmental impact and may aggravate the problem with the water contamination.

To analyse the environmental impact of this project, it can be divided into three phases:

<u>Manufacturing</u>

In this project the drone has been purchased entirely so its manufacturing hasn't been taken into account. So the manufacturing refers to the sampler and the electronic system.

The electronic system manufacture requires a big amount of resources and energy. For its fabrication, a microchip of 2 grams needs 1600 g of petroleum, 72 g of chemicals, 32000 g of water and 700 g of elemental gases [14]. The diagram in figure 28 shows the energy consumption and the chemicals needed for manufacturing a single microchip.

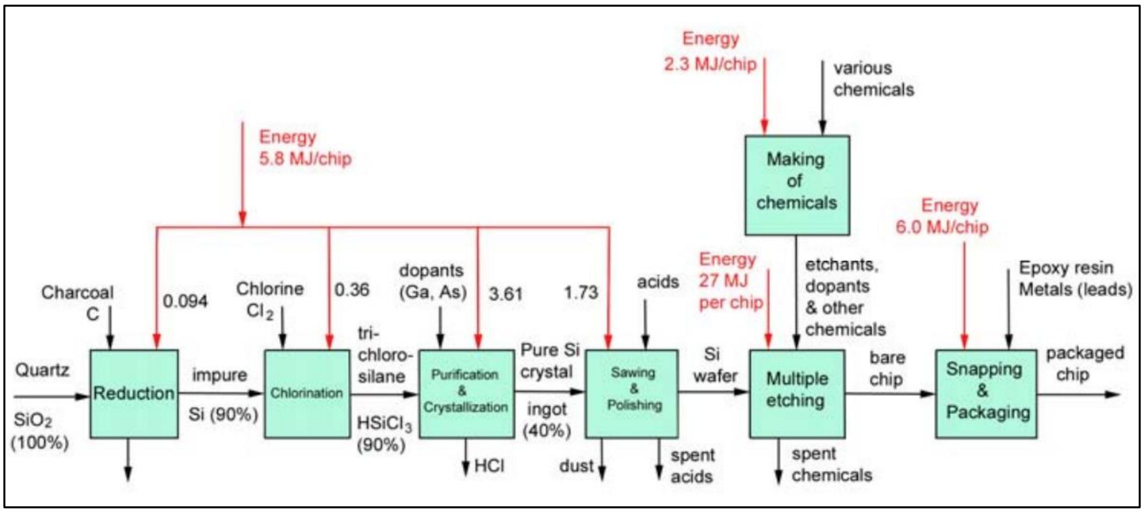

Figure 28. Diagram of energy and chemical consumption for microchip manufacturing.
Source: E. D. Williams, R. U. Ayres and M. Heller, "The 1.7 Kilogram Microchip: Energy and Material Use in Production of Semiconductor Devices," Environmental Science and Technology, *vol. 36, no. 24, pp. 5504-5510, 2002.*

For the production of a microchip 41 MJ of energy are needed and the percentage for each activity during the process are the following: 46% for ventilation and air condition in the clean-room, 35% during the fabrication of the chip and the wafer, 7% making liquid nitrogen, 7%for the manufacturing assortment of chemicals and 5% for water purification.

For the DC motor, besides the pollution due to the extraction of raw materials and their transportation, it must be taken into account the energy needed for its production. The materials used for this process are: winding electrical copper, sheet steel, impregnating varnishes and compounds, cover enamels, as well as widely diversified materials of the electrical insulation. It is important to dispose and recycle all the waste generated during this process.

Finally, the sampler, which will be produced by 3D printing, will produce some waste during the printing process. The good part is that PET is easy to recycle, and the filaments used for this process may come from recycled materials, like beverage bottles. The printing machine also produces indirect CO_2 emissions due to the energy usage. [15]

Lifetime

During the lifetime, the environmental impact is given by the energy need to power the batteries. The battery of the drone (TB47D Intelligent Flight Battery, in figure 29) is the one which provide the energy to move the drone, as well as the energy for the microcontroller and the DC motor.

Figure 29. Intelligent Flight Battery TB47D.
Source: Own work

This battery is a LiPo battery with 4500mAh capacity and 22,2V voltage.

To assess the environmental impact of the energy consumption it should be known the source of the consumed energy. To estimate the impact of the energy consumed, in table 5 are shown the percentage of renewable energy consumption for different regions.

Table 5. Percentage of renewable energy consumption in different region.

Region	**Ratio between the electricity production from renewable energies and the total electricity production**	**Ratio between the electricity production from wind and solar energies and the total electricity production**
China	26,0	6,8
Spain	32,2	22,8
Europe	33,6	13,5
World	25,9	8,0

Note: Data from Enerdata, "Global Energy Statistical Yearbook 2018," 2018.

Then, according to the data above, we can have a rough idea about the different environmental impact depending on where the drone is used, due to the different energy sources in different regions.

This project, during its lifetime, doesn't emit any waste, except for any possible failure or damage of any of its parts, in case they need to be replaced for a spare part. Also the batteries, when their lifetime expires they must be replaced for a new ones and the old ones must be disposed for recycling. But these cases are the same as the disassembly stage of the drone, and they are explained in the next section.

<u>Disassembly</u>

The disassembly is the stage at the end of the lifetime. In this stage are considered the drone, the batteries, the electronic system and the sampler.

The drone has an electronic part, which will be disposed in the same way as the other electronics, the battery, which should be disposed separately, and the structure, made of plastic and carbon fibre. The structure should be recycled, and there are different processes to do it. Carbon fibre is made of carbon fibres and plastic resin. The most common recycling processes to recover carbon fibre from waste are pyrolysis and solvolysis. Pyrolysis use a high heat to burn the resin, and it consume a huge quantity of energy. Solvolysis use a solvent to dissolve the resin, and it offers superior properties compared with pyrolysis, although it produces waste from the solvent mixed with the resin. [16]

About the electronic components, they may contain toxic substances such as lead, mercury, cadmium and chromium, so the proper processing is essential to ensure that these materials are not released into the environment. In landfills or primitive recycling operations, toxic materials can be released from the electronic components into the environment. According to UN, only 10-15 percent of gold is successfully recovered while the rest is lost; electronic waste contains deposits of precious metal estimated to be between 40 and 50 times richer than ores mined from the earth. [17]

The batteries are lithium polymer, a category of li-ion rechargeable batteries, and they must be disposed of with particular care. They cannot be disposed in landfills, as they can easily catch fire, and they shouldn't be incinerated due to the risk of explosion. This type of batteries should be discharged in salt water before they are disposed of as hazardous waste. [18]

Finally, regarding the sampler, in spite of being made of PET (a kind of polymer which can contaminate the environment if it is not disposed properly), it can be recycled or reused. One of the uses can be to make new fibres for 3D printing. It can also be used, after shredding the material into small fragments, as a raw material for polyester fibres, polyester sheets or strapping.

6. CONCLUSION

The origin of this project is the need of finding a solution to the severe and harmful state of Taihu Lake. The project answers to the water quality plan set by the government, helping to analyse water quality and monitor some parameters, to ease the treatment before its supply. And the final result of the project accomplishes the main objectives, it has been designed a device to take samples of water from the water surface, which results a greener solution compared with the traditional way.

It was a challenge to me to work on a project based on UAV technology, as I didn't work before with this kind of technology and applications, nevertheless the greatest challenge has been to develop the software. I had some knowledge about programming in C++ language, and I knew the electronic basics, but I never programmed before an entire software environment for this kind of microcontroller. It has helped me to learn a lot about these two topics: how the drone works, and all the applications that there are on the market nowadays, as so as all the new ones that are being developed every year; some of the functions a microcontroller is capable to develop, among the hundreds of applications it may have, and the laborious work of writing a code, but not that complex when the language is understood.

During my courses in Tongji University, in the College of Environmental Science and Engineering, I learnt about water treatment processes, the parameters and standards needed to monitor its quality, and be sure that it is available for its supply. I also heard about Taihu Lake case study, the problem with the presence of cyanobacteria on the surface, and how this issue affects many water sources all over the world, specially in warm places during summer season. For these reasons and my interest on sustainable development and environmental research, I was motivated to develop this project and help finding a possible solution to the problem.

I have been working with professor Li Lei research group, from CESE. He proposed me to work on this project, and told me about their needs. They are specialized in environmental science, so I could help them with the mechanics and electronics, developing this project. Nevertheless, I didn't know the methodology to take samples of water, so when I found the solution I had to talk with them to be sure it was a good solution, and at the same time they could give me advises to continue developing it. Our work together has been a synergy and both of us have learnt a lot.

The project now is a prototype, it pretends to show it is possible to take samples of water using a UAV technology, but for its professional use it is required a greater aircraft, which can take more samples and may have a longer flight autonomy. There are also some other applications the drone can develop at the same time: it can monitor some water parameters using a camera, and detect the presence of cyanobacteria to know where to take the samples. All these future research is studied in the next section.

7. FUTURE RESEARCH

As it is explained on the conclusions, this project is just a prototype to prove that the drone can be used to take samples of water from the surface with the proper technology. But for its professional use it can be used a bigger model, which can support a higher load. It has a high potential to develop many applications.

First of all, the program can be optimized, and connecting the microcontroller to the drone by USART communication, the sampler could be controlled using the same application used to control the drone and show the camera view at the same time. In this case, because of the complexity of modify the drone software to add this function, the lack of time to do it and the limitations that this model (DJI Matrice 100) has working with third parties' devices, it couldn't be developed. This is the first thing to take into account, as it is not so convenient to run another application just for the sampler.

To attach the hardware used for sampling to the drone, it has two expansion bays where the board and all the electronics, as so as the DC motor, can be fixed. It has been taken into account, but a case should be designed to maintain all the electronics safe. The drone works from a safety distance from water, but neither the drone nor the electronics can be in contact with water, as they are not waterproof, so as it will work near water surface, all these parts should be covered and isolated to prevent this contact.

Another important function the drone could develop is to detect some water parameters and the presence of cyanobacteria on the surface. This could be done using a hyperspectral imaging camera [3]. This option was studied during the pre-study, defining the project objectives, and some cameras were checked for this use (see figure 30). Table 6 shows some characteristics of these cameras.

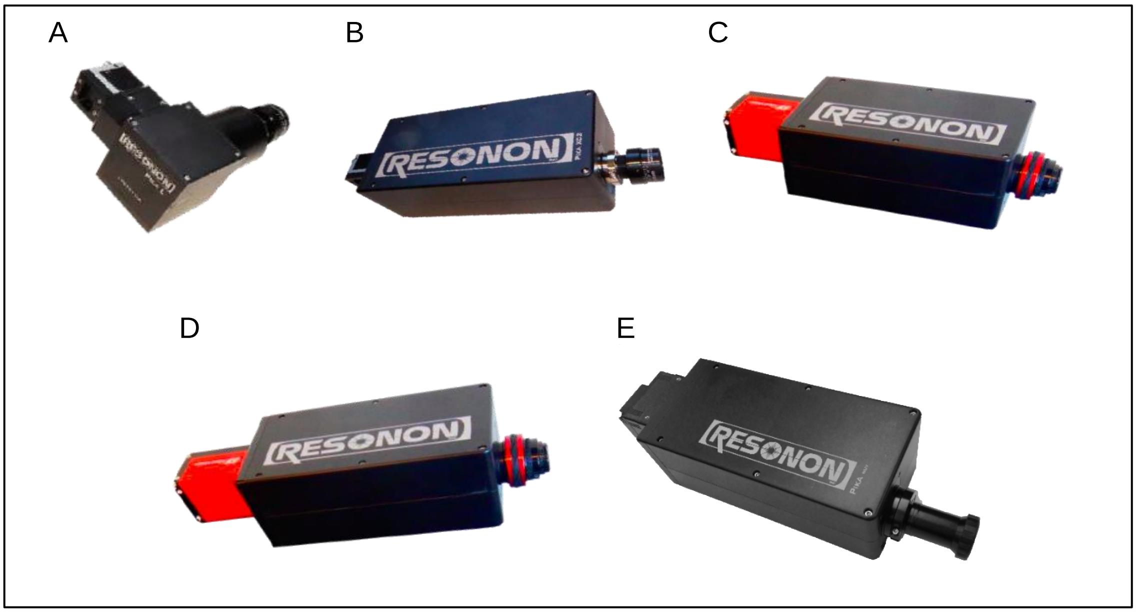

Figure 30. Some hyperspectral imaging cameras to assess water from the drone. A: Resonon Pika L; B: Resonon Pika XC2; C: Resonon Pika NIR-320; D: Resonon Pika NIR-640; E: Resonon Pika NUV. Source: https://resonon.com/hyperspectral-cameras

Table 6. Hyperspectral imaging cameras specifications.

	Pika L	Pika XC2	Pika NIR-320	Pika NIR-640	Pika NUV
Spectral range (nm)	400 – 1000	400 – 1000	900 – 1700	900 – 1700	350 – 800
Spectral resolution (nm)	2,1	1,3	4,9	2,5	2,3
Spectral Channels	281	447	164	328	196
Spatial Channels	900	1600	320	640	1600
Max frame rate (fps)	249	165	520	249	165
Bit Depth	12	12	14	14	12
Weight (kg)	0,6	2,2	2,7	2,7	2,1
Dimensions (cm)	10 x 12,5 x 5,3	10,1 x 27,5 x 7,4	11 x 29,6 x 8,9	11 x 29,6 x 8,9	10,1 x 26,4 x 7,4
Connection type	USB 3.0	USB 3.0	GigE	GigE	USB 3.0

Note: Data from https://resonon.com/hyperspectral-cameras

Among the cameras listed on table 4, the best option for its characteristics and its weight is Pika L, which has a wide spectral range, a good resolution, and the weight and size (which are two of the most important characteristics in this case because of the restrictions given by the drone) are much less than the others. This camera will help to detect the presence of cyanobacteria in water surface, and also give its temperature and turbidity.

Nevertheless, to add the camera and any other device it is needed another drone, as the one used in this project, DJI Matrice 100, can't take off with a load greater than 1kg, which means it can't carry the sampler and the camera at the same time. To solve this problem, another drone should be used, and the best option of the same brand is DJI Matrice 600 (see figure 31), which has 6 propellers, 6 batteries and a flight time from 18 to 40 minutes, depending on the load, which can be up to 6 kg, enough to attach the camera and the sampler at the same time, and even take more than one sample. If it is used this drone, the software should change but can maintain the same hardware, with the same microcontroller.

Figure 31. DJI Matrice 600 drone.
Source: https://www.dji.com/es/matrice600

8. NORMATIVES AND REGULATIONS

This section is the outline of the regulations that apply the use of unmanned aerial vehicles in Spain, as well as the regulations and normative about water sampling and drinking water standards for human use.

- *Real Decreto 1036/2017, de 15 de diciembre, por el que se regula la utilización civil de las aeronaves pilotadas por control remoto, y se modifican el Real Decreto 552/2014, de 27 de junio, por el que se desarrolla el Reglamento del aire y disposiciones operativas comunes para los servicios y procedimientos de navegación aérea y el Real Decreto 57/2002, de 18 de enero, por el que se aprueba el Reglamento de Circulación Aérea.*

  This decree, applicable throughout the Spanish state, regulates the use of unmanned aerial vehicles and establishes the necessary permits to flight this kind of vehicles within the Spanish territory.

- *Real Decreto 902/2018, de 20 de julio, por el que se modifican el Real Decreto 140/2003, de 7 de febrero, por el que se establecen los criterios sanitarios de la calidad del agua de consumo humano.*

  This decree, applicable throughout the Spanish state, establishes the standards and healthy criteria for drinking water quality, and the parameters to allow its use for human consumption.

- Guidelines for drinking-water quality, fourth edition.

  This document builds on over 50 years of guidance by WHO on drinking-water quality, which has formed an authoritative basis for the setting of national regulations and standards for water safety in support of public health.

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